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Global Persistent SAR Sampling with the NASA-ISRO SAR (NISAR) Mission

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Outline

- Scientific Observation Requirements and Trends for SAR
- NASA-ISRO Synthetic Aperture Radar (NISAR) mission overview
- Are there other ways to achieve a NISAR-class SAR mission?

SAR for Science and Applications

Area	Benefit Through Regular SAR Monitoring of:
Global Food Security	- Soil moisture and crop growth at agricultural scale - Desertification at regional scales
Freshwater Availability	- Aquifer use/extent regionally - Water-body extent changes - Glaciers serving as water sources
Human Health	- Moisture and vegetation as proxy for disease and infestation vectors
Disaster Prediction & Hazard Response	- Regional building damage and change assessment after earthquakes - Earthen dams and levees prone to weakening - Volcanoes, floods, fires, landslides
Climate Risks and Adaptation	- Ice sheet/sea-ice dynamics; response to climate change - Coastal erosion and shoreline migration
Urban Management and Planning	- Urban growth through coherent change detection - Building deformation and urban subsidence
Human-activity Based Climate Change	- Deforestation's influence on carbon flux - Oil and gas reservoirs

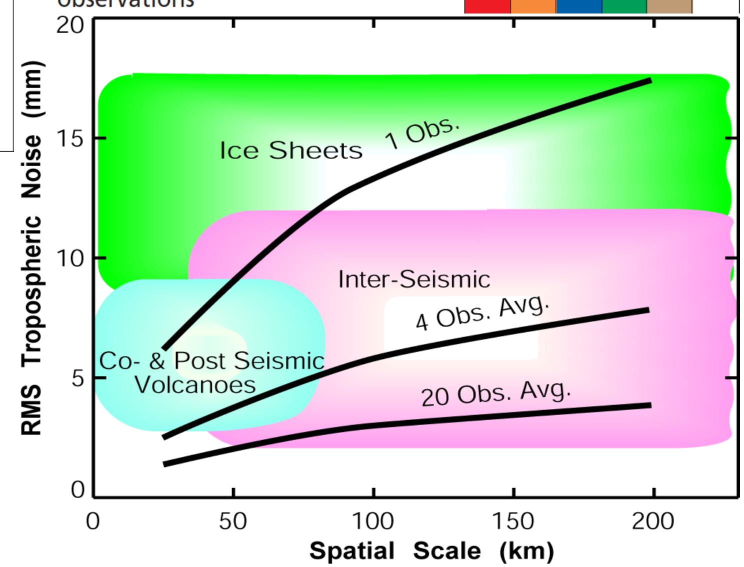
Toward Global Sampling with SAR

- Since SEASAT in 1978, the US science community has been looking forward to a free-flying SAR mission
- It has not been for lack of trying:
  - Selected community recommendations:
    - 1994 Letter to NASA ESD recommending a free-flying SAR at L-band in 8-day repeat
    - 2002 SESWG Report ”InSAR everywhere all the time”
    - 2002 EarthScope Executive Committee recommending InSAR as the 4th pillar of EarthScope
    - 2004 SAR Workshop and Report recommending L-band Polarimetric SAR
    - 2007 Decadal Survey recommending DESDynI long-wavelength polarimetric radar
  - Proposals
    - 1994-1995 SIR-C free-flyer proposal
    - 1996 LightSAR commercial/science dual use L-band and X-band earmark
    - 1996 ESSP ECHO-1
    - 1998 ESSP ECHO-2
    - 2002 ESSP ECHO-3
    - 2004 InSAR Satellite Concept
    - 2004-2007 defense/science dual use broad-band SAR
    - 2007-2011 DESDynI L-band SAR

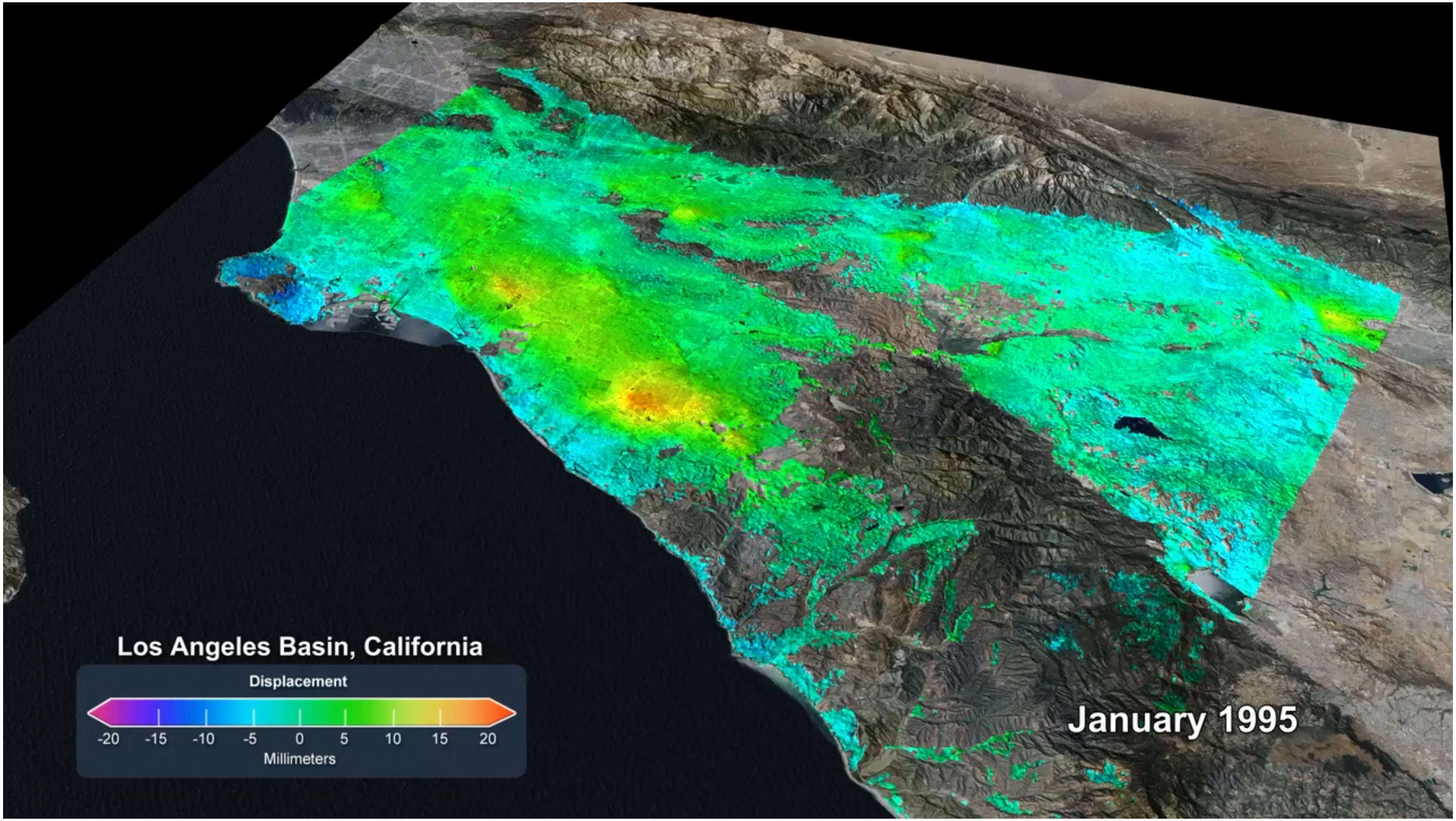
Recommendation from 2002 Solid Earth Science Working Group Report

Timeline / Observational Strategies	Immediate (1–5 Years)	Near Term (5–10 Years)	Long Term (10–25 Years)	Plate Boundaries	Land Surface Change	Ice and Ocean Dynamics	Magmatic Processes	Mantle Dynamics	Magnetic Field
Surface deformation	Single dedicated InSAR satellite • L-band, left/right looking capability, and weekly access to anywhere on the globe • Precise orbit determination and ionospheric correction capabilities • 1 mm/yr surface displacement over 50-km horizontal extents in selected areas	Constellation of InSAR satellites • Improved temporal frequency of deformation maps to daily intervals • Maps at several-hundred-km width with full vector surface displace ments at accuracies of submillime- ter per year over 10-km spatial extents and 1-m spatial resolution • Complementary ground and seafloor geodetic observations	Constellation of InSAR satellites in low-Earth or geosynchronous orbits • Hourly global access • Increased density of continuous ground and seafloor geodetic observations						

- Community has bold vision for continuous monitoring of Earth's solid earth processes
- Requires dense spatial and temporal sampling



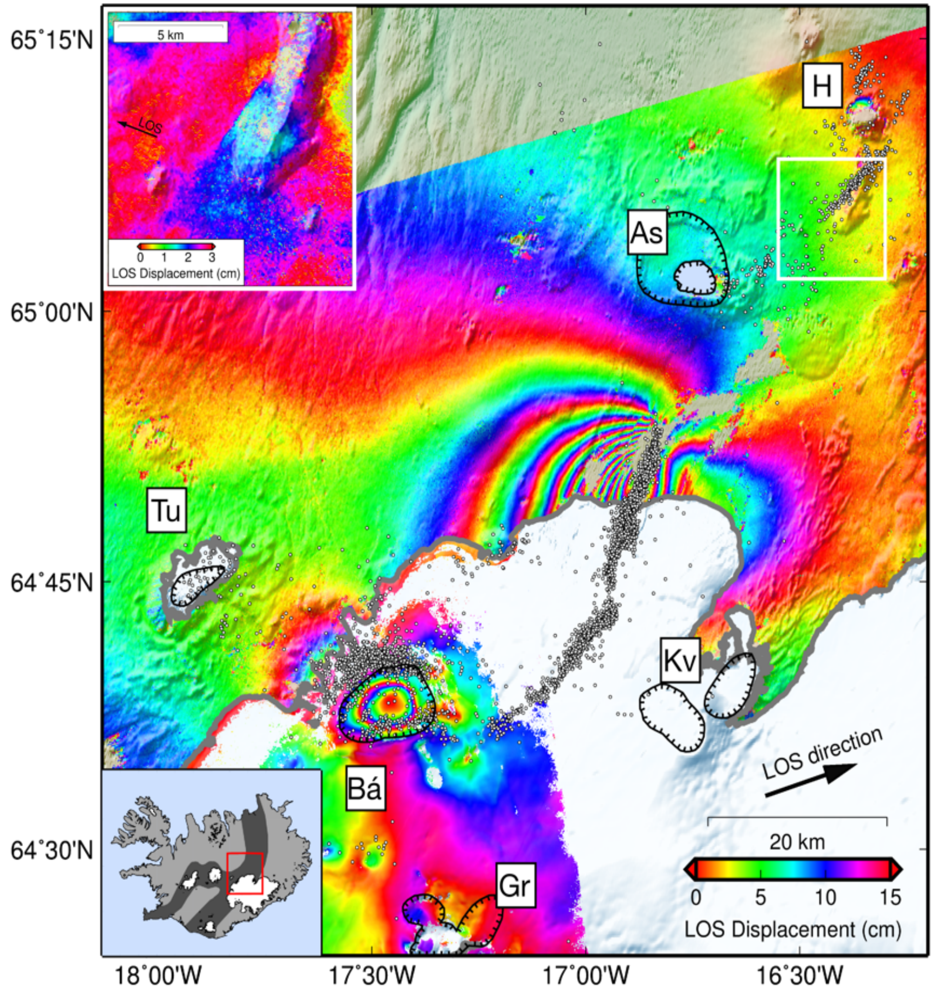
Measuring Aquifer Usage In Los Angeles

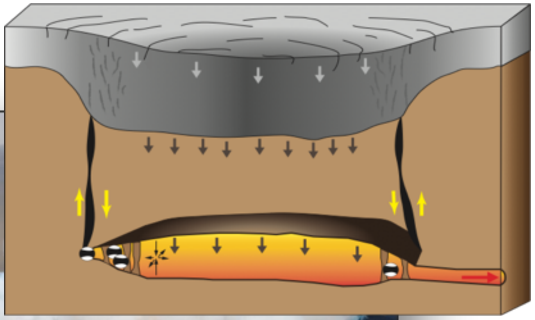


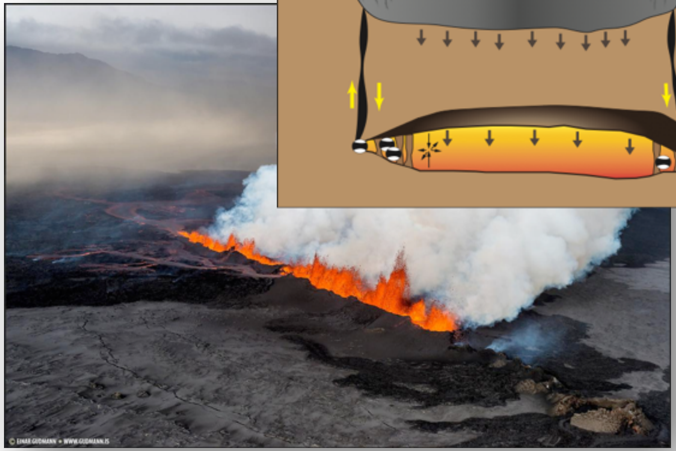
jpl.nasa.gov

Fast sampling permits imaging dynamics

COSMO-SkyMed (1-day) fills in Radarsat-2 (24-day) pairs



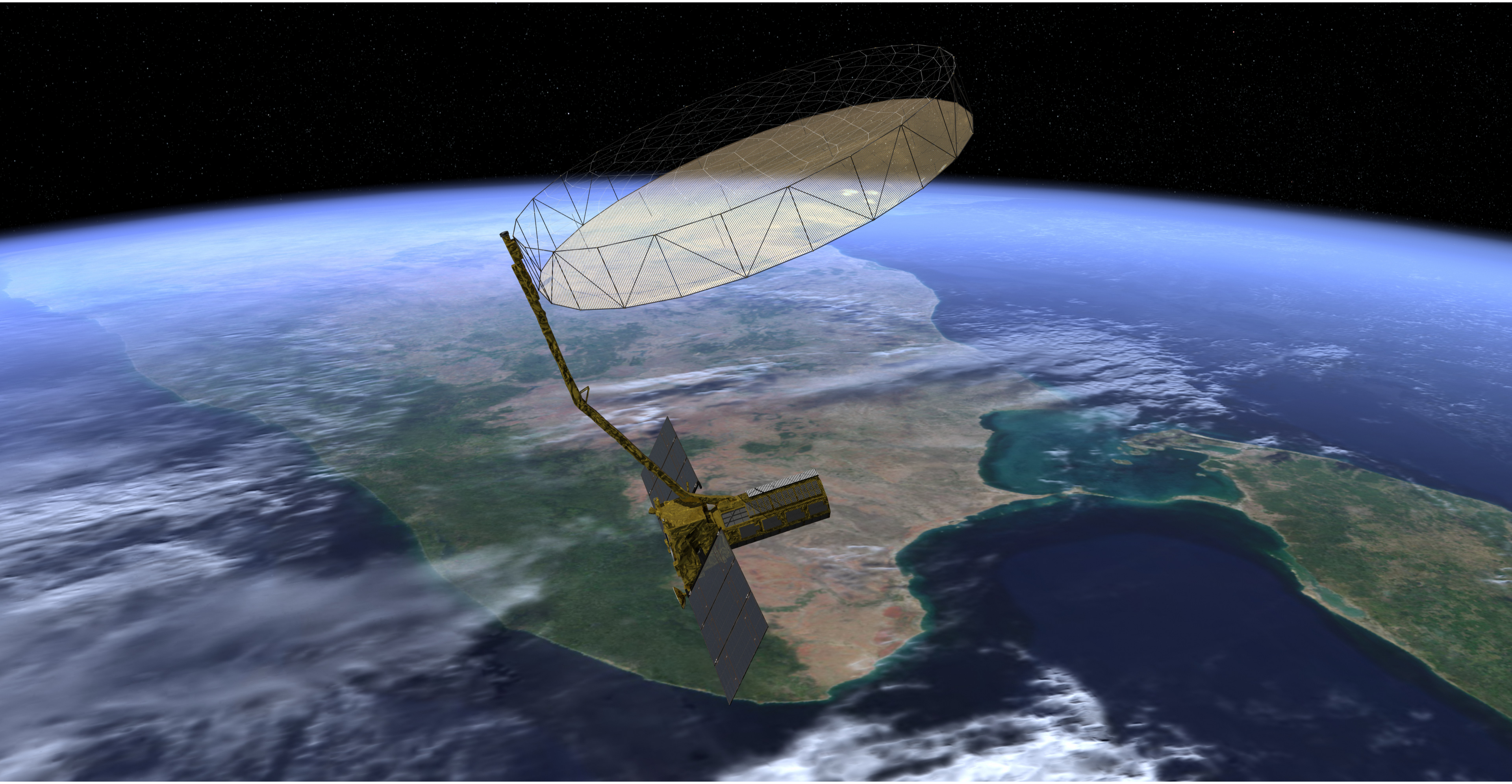




Collapse of Bárdabunga Caldera (Iceland) & associated plate boundary rifting

Riel et al., *Geophys. J. Int.*, 2015

NASA-ISRO SAR (NISAR) Mission
http://nisar.jpl.nasa.gov



NISAR Mission Overview

NISAR Characteristic:	Would Enable:
L-band (24 cm wavelength)	*Low temporal decorrelation and foliage penetration*
S-band (12 cm wavelength)	*Sensitivity to light vegetation*
SweepSAR technique with Imaging Swath > 240 km	*Global data collection*
Polarimetry (Single/Dual/Quad)	*Surface characterization and biomass estimation*
12-day exact repeat	*Rapid Sampling*
3 – 10 meters mode-dependent SAR resolution	*Small-scale observations*
Pointing control < 273 arcseconds	*Deformation interferometry*
Orbit control < 500 meters	*Deformation interferometry*
> 30% observation duty cycle	*Complete land/ice coverage*
Left/Right pointing capability	*Polar coverage, north and south*

Cryosphere

Solid Earth

Applications

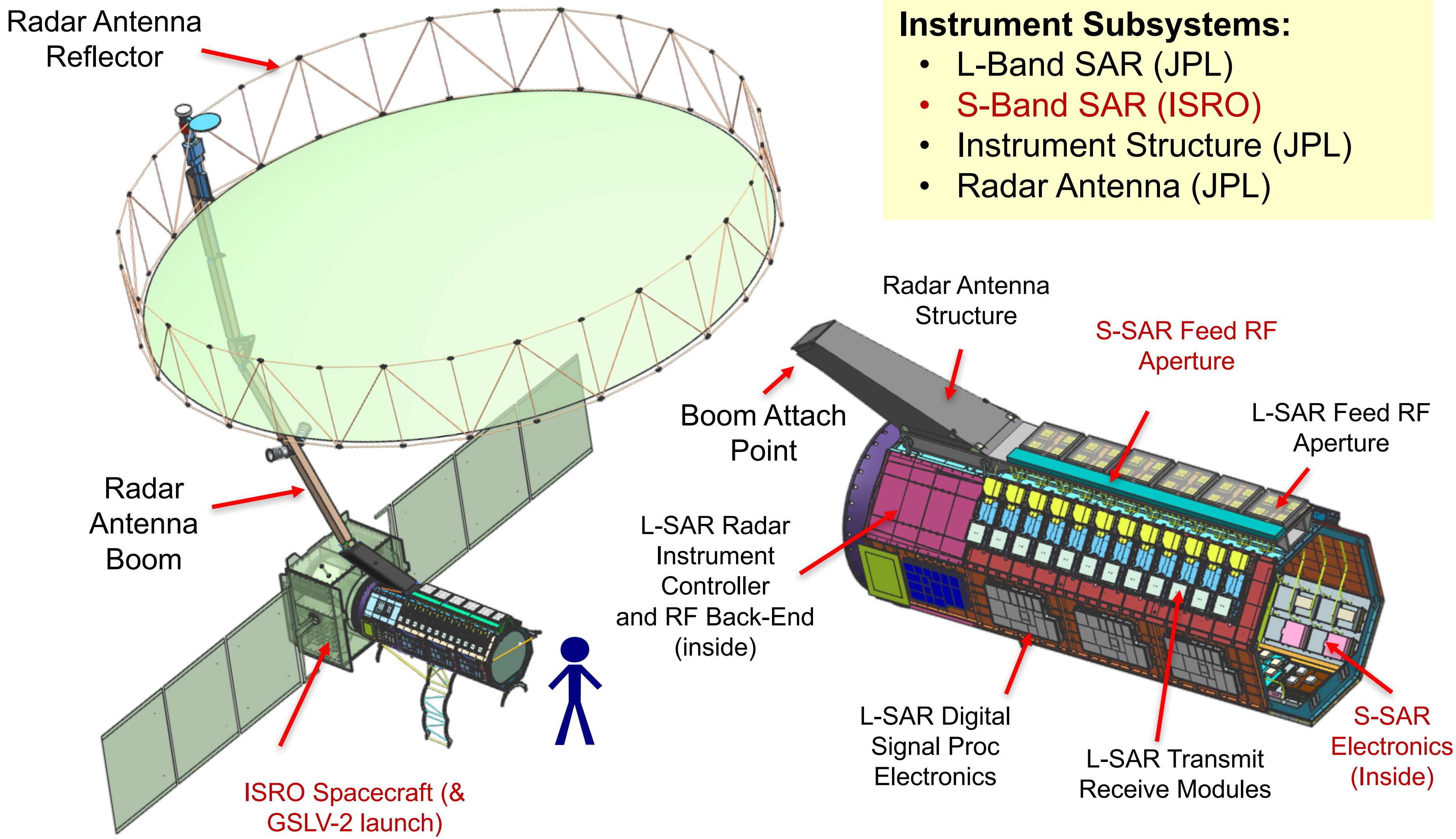
Ecosystems

Key NISAR characteristics capture Earth in motion:

- *Dense temporal and spatial sampling*
- *Comprehensive global measurements*
- *Targeted new science observations*
- *Free and open data policy*

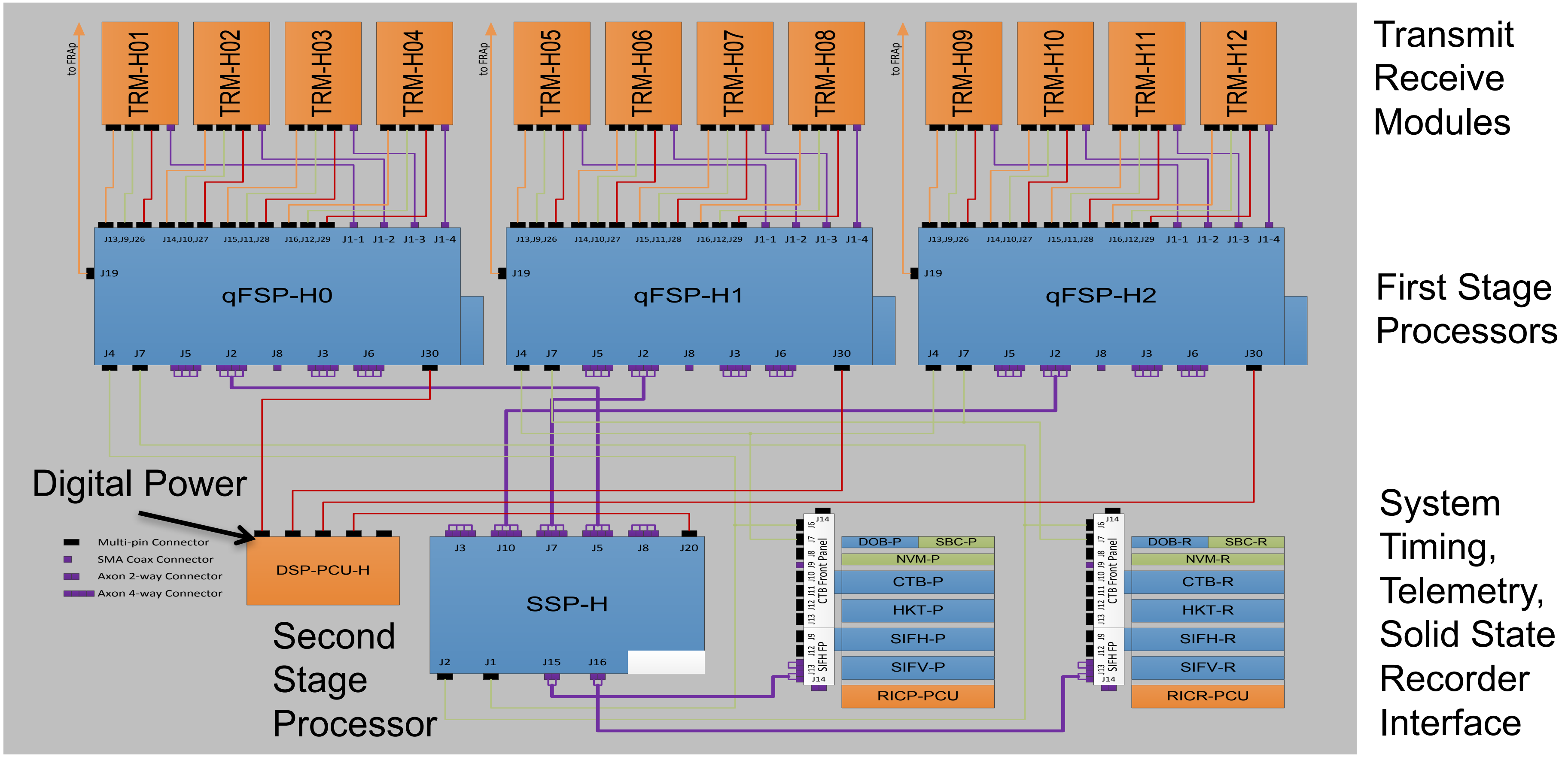
NISAR Observatory

Instrument Subsystems:
- L-Band SAR (JPL)
- S-Band SAR (ISRO)
- Instrument Structure (JPL)
- Radar Antenna (JPL)



Instrument Structure also houses GPS unit and Solid State Recorder

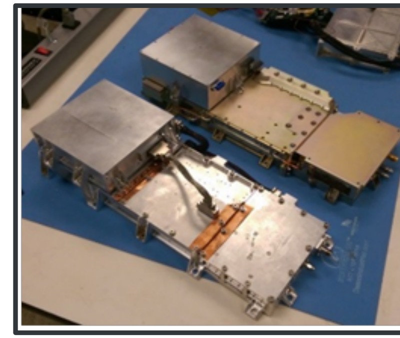
L-SAR Architecture (Only Horizontal Polarization Shown)



NISAR L-band Radar Electronics

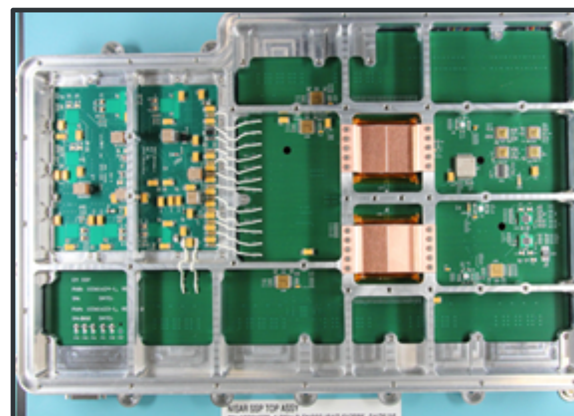
Radar Computer (2)

Waveform generator and up-converter (2)



Transmit-Receive Modules (24)

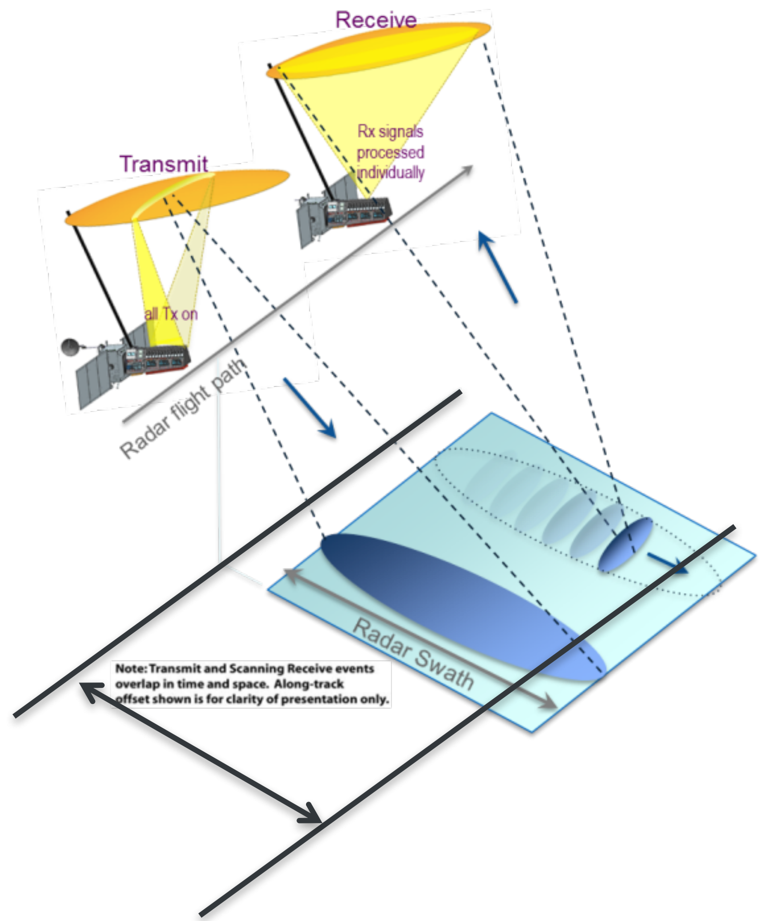
Radar Digitizer, Decimator and First-stage Beamformer (6)



Second-stage Beamformer and Formatter (2)

NISAR Swath Coverage

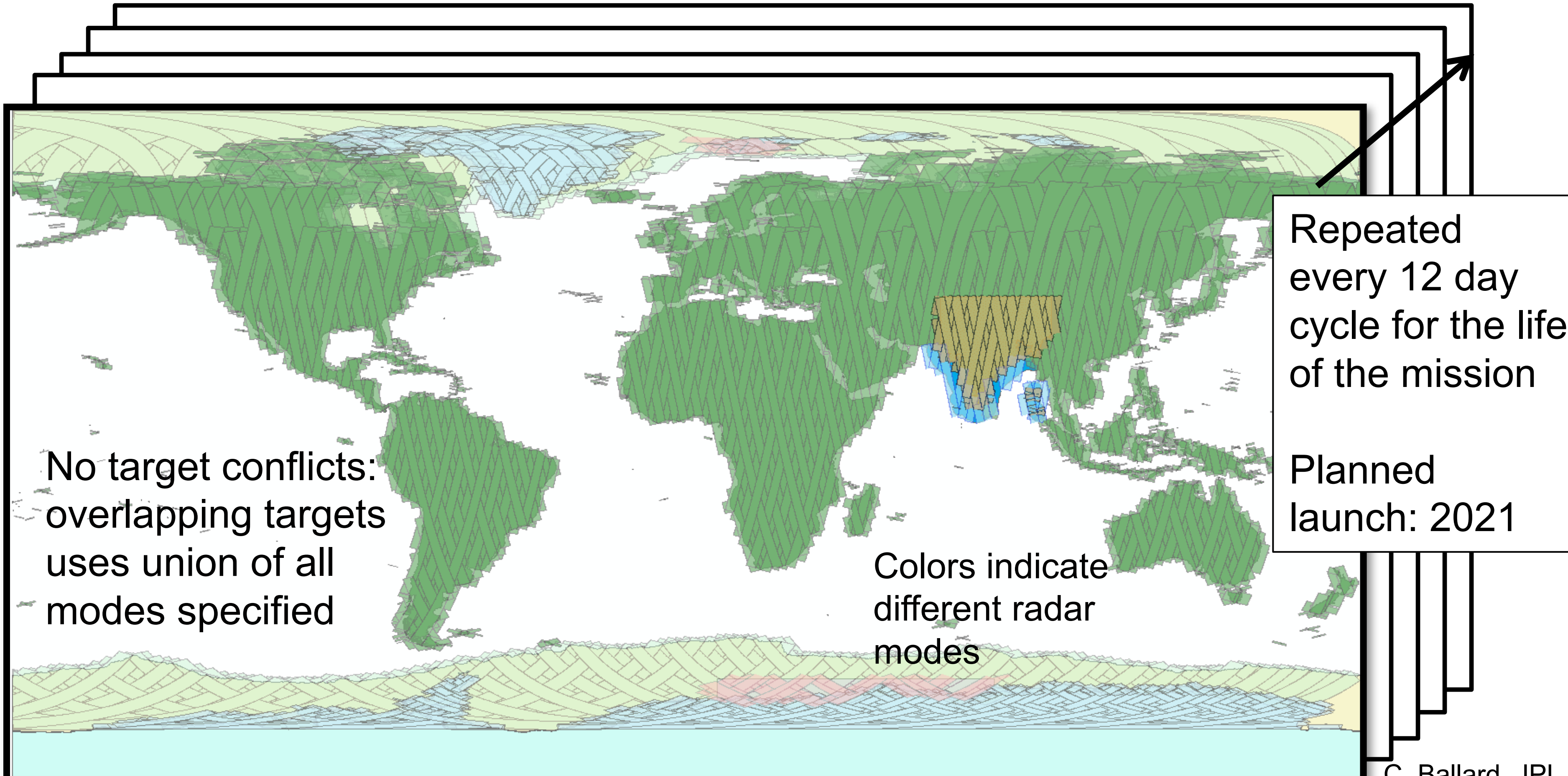
- All science disciplines require frequent coverage over global targets
- NISAR approach would acquire sufficient swath to cover equatorial ground track extent
  - ➔ Global access at desired time sampling and imaging characteristics
- *SweepSAR* technology being implemented independently by both JPL and ISRO
  - Transmit pulse with full feed illumination
  - Track echo digitally with individual receivers (12 at L-band; 24 at S-band)
  - Assemble individual receivers into a full-swath measurement



~236 km Earth-fixed ground track spacing at equator for 12-day repeat orbit

NISAR Systematic Observations

L-band globally – S-band over selected areas



C. Ballard, JPL

- Six-day or shorter sampling of Earth – 3 petabyte of raw data per year
- Required to track dynamic changes and mitigate noise in three discipline areas
- 77% chance of observing any location at US latitudes within 4 days of a disaster

What about a constellation of satellites to achieve same capabilities?

- Constellations of smaller, standardized satellites are being developed to lower cost and develop commercial markets

Capability	NISAR	Small SAR
Wavelength	L and S-band	X through L various
Repeat Pass Interferometry – orbit and pointing control	< 0.1^{o} pointing stability < 300 m orbit tube	?
12-day sampling – wide swath	240 km strip	~30 km strip
Polarimetry – aperture size and power, data rate and volume	SP-QP: 12 m diameter aperture	SP-QP: ~5-10 sqm
Resolution – data rate and volume	3-10 m res ~ 1 Gbps	3-10 m res ?
Persistent Global coverage – on-orbit duty cycle	> 50%	~10%

Number of small SAR satellites to achieve NISAR

NISAR Swath — NISAR L-band duty cycle

$$N_L = \frac{240 \times 0.5}{S \times T_o}$$

smallSAR Swath — Small SAR duty cycle

NISAR S-band duty cycle

$$N_S = \frac{240 \times 0.1}{S \times T_o}$$

- Under assumptions on previous page
  - 40 L-band radar satellites
  - 8 S-band radar satellites

What about continuity beyond NISAR? Or Densification?

- NISAR represents the first step toward SESWG and continuing community recommendations
  - 1-day repeat
  - Global coverage
  - Finer resolution
  - Greater vector diversity
  - Multi-decade time series
- Means for continuity in the age of affordability
  - International coordination
  - SmallSAT constellations (Public and private)
  - Rethink science requirements

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